

Short communication

Geochemical characteristics of the widespread Tahuna Tephra

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Abstract The c. 40 000 yr Tahuna Tephra found throughout the central North Island, New Zealand, and offshore in the Bay of Plenty, is considered to have erupted from the Okataina Volcanic Centre. Its glass and mineral chemistry, eruption temperature, and fO_2 are dissimilar to Okataina-sourced Mangaone Subgroup tephra with which it is interbedded in the Bay of Plenty. Instead, Tahuna Tephra displays a compositional affinity to pre-22 000 yr tephra from Taupo Volcanic Centre. A Taupo source is also more consistent with the tephra's thickness and coarseness at Lake Poukawa in southern North Island.

Keywords Tahuna Tephra; Okataina Volcanic Centre; Taupo Volcanic Centre; tephra; tephrochronology; Mangaone Subgroup

INTRODUCTION

The stratigraphy and source of post-c. 60 000 yr old rhyolitic tephra beds in New Zealand are generally considered to be well constrained (e.g., Froggatt & Lowe 1990; Shane 2000). However, the record of tephra beds before the Last Glacial Maximum is affected by erosion and tephric loess deposition, and their outcrop is discontinuous. In particular, the pre-22 000 yr eruptive record of Taupo Volcanic Centre (TVC) is only partially reconstructed (Vucetich & Howorth 1976), and caldera formation has obliterated proximal exposures.

The Tahuna Tephra is a widespread unit (Fig. 1) found interbedded with older units of the Mangaone Subgroup tephra (Howorth 1981) from Okataina Volcanic Centre (OVC) in the Bay of Plenty area (Howorth 1975). North of Lake Taupo, it is interbedded with TVC tephra (Vucetich & Howorth 1976). The Tahuna Tephra has not been directly dated but is considered to be c. 42 000 yr old (Froggatt & Lowe 1990). Optical luminescence data suggest it could be post-40 000 yr (Lian & Shane 2000). Although assigned to the OVC, the lithological character of Tahuna Tephra differs from other Mangaone Subgroup deposits in that it consists mostly of fine to medium ash dispersed uniformly

throughout the Bay of Plenty region. Its dispersal does not clearly demonstrate an OVC source (Fig. 1).

The Tahuna Tephra is a useful tephra marker bed in the late Quaternary because it is particularly widespread (Fig. 1), and in the central North Island it is characterised by a distinctive pink to mauve colour and a fine ash texture, allowing it to be easily identified in the field. It has been identified in a deep-sea core some 140 km offshore of the Bay of Plenty coast (Pillans & Wright 1992), and also in the Waikato lakes region (Green & Lowe 1985; Lowe 1986). It erupted during a period when the climate was cooler than present (McGlone et al. 1984), and occurs in sequences that contain erosional boundaries at many central North Island localities. We present geochemical data on its glass and phenocryst phases, in an attempt to identify a potential source volcano.

GEOCHEMISTRY AND MINERALOGY

We have examined the Tahuna Tephra at localities that cover much of its known dispersal (Fig. 1). Glass shards and phenocryst components were analysed from several exposures to confirm correlation, to test variation within the unit, and to compare it to other tephra. Tahuna Tephra is a calc-alkaline rhyolite with a SiO_2 content of c. 77.5 wt%, after recalculation to 100% on a volatile-free basis (Table 1). The glass composition is typical of Taupo Volcanic Zone (TVZ) tephra, but is characterised by high K_2O content (>4 wt%). This contrasts with Mangaone Subgroup tephra interbedded with Tahuna Tephra, namely Ngamotu, Maketu, Te Mahoe, Hauparu, and two previously undescribed units, that we have analysed (Fig. 2). The two previously undescribed units are found at site 50 (V16/419368, NZMS 260 grid reference) (Fig. 1). Tephra 1 occurs beneath Ngamotu Tephra and is separated from it by a paleosol. Tephra 2 overlies a paleosol and Tahuna Tephra. These interbedded tephra have K_2O contents of <3 wt% and display lower SiO_2 contents than that of Tahuna Tephra.

Subunits within the Tahuna Tephra can be distinguished at some sites on the basis of grain size and colour: fine white ash, fine mauve ash, and the coarser brown lapilli. However, these units cannot be simply traced over long distances. We analysed glass from different stratigraphic levels within the Tahuna Tephra and from different lithologies (Table 1). No significant differences were found. This suggests that, although the beds represent different eruptive events, they all belong to the same eruptive episode. The lack of paleosol development between the beds indicates no prolonged hiatuses. Correlation between sites is supported by the similarity in glass chemistry (Table 1).

The phenocryst assemblage of Tahuna Tephra contains abundant plagioclase. The ferromagnesian mineral fraction comprises orthopyroxene and hornblende in variable

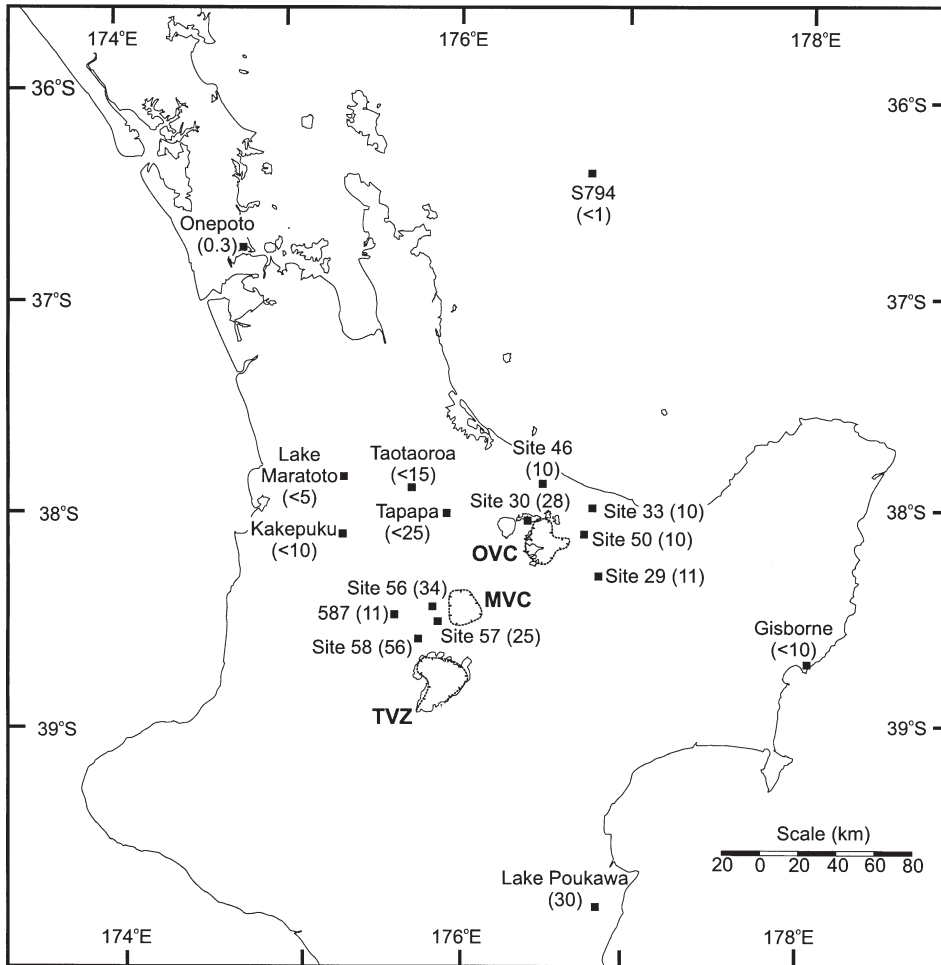


Fig. 1 Map of central North Island showing sites of Tahuna Tephra examined in this study. Thickness shown (in centimetres). Also shown are sites to depict its known extent: core S794 (Pillans & Wright 1992); Lake Maratoto, Taotaoroa, Tapapa, and Kakepuku (Green & Lowe 1985; Lowe 1986); and Gisborne (McGlone et al. 1984). Thickness at Taotaoroa, Tapapa, and Kakepuku are approximate because the tephra is not separated from Ngamotu Tephra in Lowe (1986). MVC = Maroa Volcanic Centre.

Table 1 Glass chemistry of Tahuna Tephra.

Site	SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	Cl	Water
30C (mid)	77.68	0.15	12.25	1.13	0.08	0.06	0.99	3.51	4.00	0.14	6.01
	0.21	0.07	0.16	0.10	0.06	0.04	0.10	0.15	0.12	0.03	1.10
30B (base)	77.55	0.18	12.23	1.05	0.06	0.08	1.01	3.58	4.09	0.15	4.14
	0.22	0.07	0.09	0.07	0.05	0.04	0.08	0.15	0.09	0.03	1.60
33C (base)	77.30	0.21	12.42	1.18	0.06	0.04	1.02	3.49	4.12	0.15	4.38
	0.29	0.05	0.11	0.15	0.03	0.03	0.05	0.08	0.08	0.03	1.89
58C (top)	77.69	0.19	12.27	1.03	0.06	0.10	0.92	3.37	4.22	0.15	6.50
	0.30	0.06	0.21	0.12	0.03	0.09	0.07	0.24	0.25	0.03	0.97
58B (mid)	77.76	0.19	12.23	1.09	0.05	0.08	0.94	3.42	4.11	0.12	6.13
	0.20	0.06	0.17	0.06	0.03	0.09	0.06	0.13	0.09	0.02	1.02
587	77.56	0.16	12.57	1.04	0.07	0.08	0.97	3.56	4.01	0.19	4.02
	0.18	0.05	0.1	0.09	0.04	0.06	0.05	0.11	0.05	0.02	1.79
Poukawa	77.18	0.18	12.51	1.12	0.05	0.09	1.02	3.68	3.97	0.18	4.17
	0.1	0.05	0.07	0.06	0.04	0.06	0.04	0.08	0.07	0.02	1.01
Onepoto	77.31	0.21	12.23	1.01	0.06	0.14	1.06	3.68	4.10	0.20	3.75
	0.24	0.07	0.11	0.11	0.04	0.06	0.04	0.13	0.08	0.03	1.22

Analyses recalculated to 100% on a volatile-free basis and presented as a mean (top) and standard deviation (bottom) on 10 shards. Water by difference. All Fe recalculated as FeO. Analysed by a JEOL JXA-5A probe fitted with a Link Systems LZ-5 EDS detector at the University of Auckland. Absorbed current 0.6 nA at 15 kV. Beam defocussed to 15 µm diameter.

30C = lithic-rich coarse ash, U15/095449; 30B = fine mauve ash, U15/095449; 33C = fine mauve ash, V15/395561; 58C = fine lapilli, T17/486848; 58B = coarse white ash, T17/486848; 587 = coarse ash, T17/374997; Poukawa = Lake Poukawa core, V22/515270 (Shane et al. in press); Onepoto = Onepoto basin core, R11/667866.

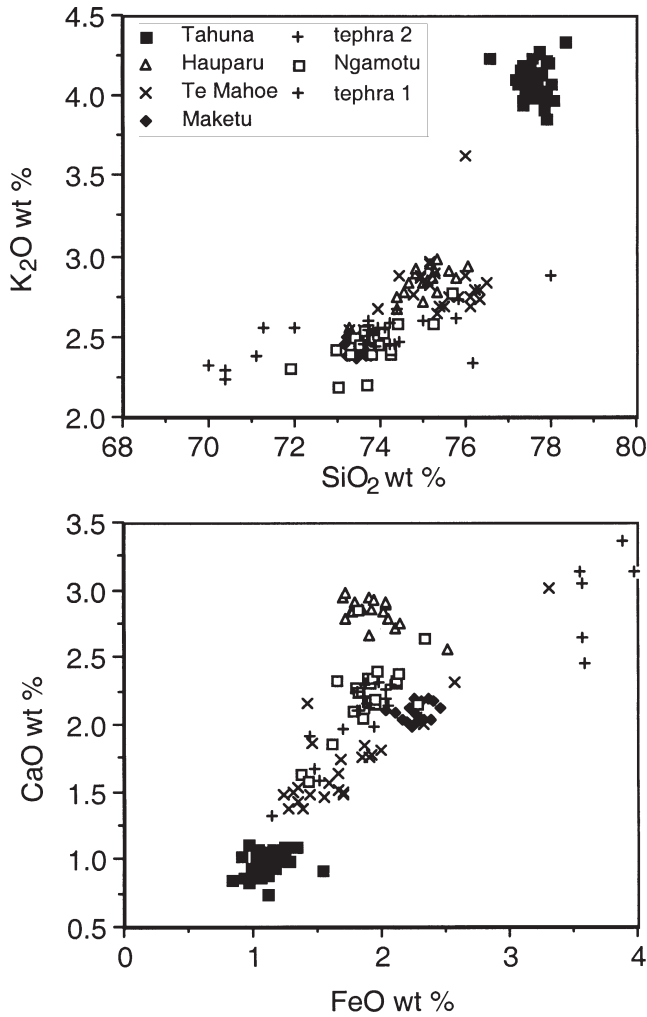


Fig. 2 Composition of individual glass shards within Tahuna Tephra compared with those from Mangaone Subgroup tephra beds (V. Smith unpubl. data) found in the same stratigraphic sequences.

proportions, but hornblende is usually dominant. Spinel also occurs as a phenocryst phase, while ilmenite occurs as micro-inclusions in orthopyroxene. We noted trace amounts of biotite in a yellow-brown lapilli unit at site 30 (U15/095449),

and in a mauve ash bed at site 58 (T17/486848). The plagioclase compositions in the Tahuna Tephra are mostly in the range An_{27-40} , although some more calcic compositions are also present (Fig. 3). Core and rim analyses do not reveal any significant zoning. This compositional range contrasts with that of the interbedded Mangaone Subgroup tephra, which contain plagioclase that is distinctly more calcic, mostly An_{40-55} (Fig. 3).

Orthopyroxenes within the Tahuna Tephra are compositionally uniform, and electron microprobe analyses do not reveal any significant zoning. Tahuna Tephra orthopyroxene compositions are in the narrow range En_{50-55} . This contrasts with interbedded Mangaone Subgroup tephra that contain orthopyroxenes distinctly more Mg-rich ($>En_{60}$) (Fig. 3). The other Mangaone Subgroup beds (Ngamotu, Maketu, Hauparu, and Te Mahoe) contain clinopyroxene that distinguishes them from Tahuna Tephra.

Amphiboles within Tahuna Tephra are calcic-hornblendes. Core and rim analyses revealed no indication of zoning. Hornblende within the Tahuna Tephra can be distinguished from other Mangaone Subgroup tephra by higher FeO (Fig. 4) and K_2O contents. We also analysed crystals from hornblende-rich tephra erupted from TVC that are interbedded with Tahuna Tephra near Lake Taupo (Tihoi, Okaia, and Kawakawa). Hornblendes from these TVC tephra are also FeO-rich and are compositionally similar to Tahuna Tephra. TVC hornblendes differ from those in Mangaone Subgroup beds (Fig. 4).

Studies have shown that the composition of spinel can be used to distinguish TVC tephra from OVC tephra (Shane 1998). We analysed the spinel phase within Tahuna Tephra to compare with those in tephra from the TVC and Mangaone Subgroup beds. Spinel compositional data show that Tahuna Tephra is more similar to TVC tephra beds (Fig. 5). We calculated eruption temperature and oxygen fugacity (fO_2) for Tahuna Tephra from three beds: (1) the uppermost lapilli bed at site 58 (Fig. 1); (2) the entire ash unit at site 587 (T17/374997); and (3) biotite-bearing lapilli at site 30 (Fig. 1). Temperature and fO_2 estimates were made from analyses of Fe-Ti oxide pairs using the method of Ghiorso & Sack (1991). Samples from (1) and (2) produced temperatures of 770–800°C, and fO_2 estimates are 1.0–1.2 log units above the FMQ buffer (Fig. 6). The biotite-bearing horizon (3) produced lower temperatures (710–750°C). These lower

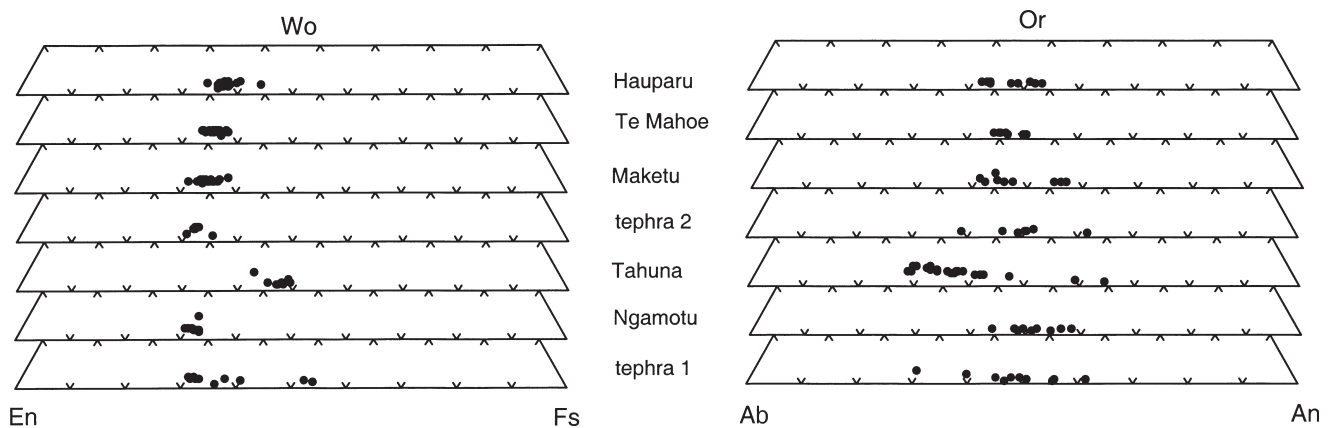


Fig. 3 Plagioclase and pyroxene phenocryst compositions for Tahuna Tephra and older Mangaone Subgroup units (V. Smith unpubl. data). Data represent core and rim analyses.

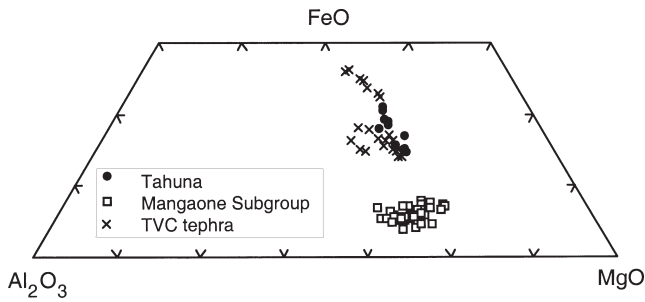


Fig. 4 MgO-Al₂O₃-FeO composition (in wt%) of hornblende phenocrysts in Tahuna Tephra compared to those within Mangaone Subgroup units and TVC units (Tihoi, Okaia, and Kawakawa) (Smith & Shane unpubl. data). Data represent core and rim analyses.

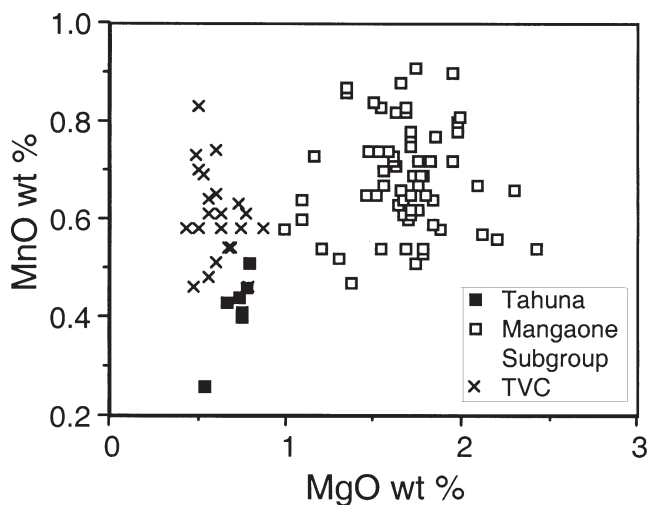


Fig. 5 Composition of individual spinel crystals in Tahuna Tephra compared to those in Mangaone Subgroup beds (Ngamotu, Maketu, Te Mahoe, Hauparu, and two newly recognised beds), and TVC beds (Tihoi, Okaia, Kawakawa) (Shane & Smith unpubl. data).

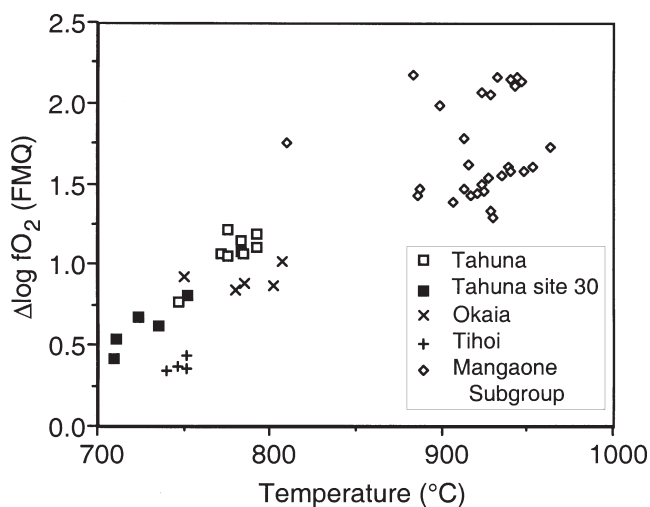


Fig. 6 Temperature versus $\Delta \log f_{O_2}$ (FMQ) plot based on data from Fe-Ti oxide pairs in Tahuna Tephra, older Mangaone Subgroup units, and TVC units (Tihoi and Okaia). Tahuna site 30 data are from a biotite-bearing unit (Shane & Smith unpubl. data). $\Delta \log f_{O_2}$ (FMQ) = distance above the fayalite-magnetite-quartz buffer.

temperatures are consistent with the occurrence of biotite and suggest this layer represents a different eruptive phase, but is still part of the Tahuna Tephra because it displays the same glass chemistry. In contrast, the older Mangaone Subgroup units are characterised by temperatures $>900^{\circ}\text{C}$, and f_{O_2} values >1.5 log units above the FMQ buffer (Fig. 6). Temperature and f_{O_2} values for Tahuna Tephra are similar to those of Tihoi and Okaia Tephra beds from TVC (Fig. 6).

DISCUSSION

The Tahuna Tephra is geochemically dissimilar to Mangaone Subgroup tephra with which it is interbedded. This may provide evidence for its source. OVC and TVC are both characterised by eruptive periods of 10–20 000 yr when tephra of similar composition are produced that display a common T- f_{O_2} trend. These periods are then followed by distinct changes in tephra composition (Shane 1998, 2000; Sutton et al. 2000). The Tahuna Tephra does not show any chemical or mineralogical affinity to the older units of the Mangaone Subgroup from the OVC. The Ngamotu, Maketu, Te Mahoe, Hauparu, and two previously undescribed units display a common chemical and mineralogical affinity. These units are clinopyroxene-bearing rhyodacites, with high temperature and f_{O_2} , and low SiO₂, that are distinctly different from the Tahuna Tephra. The Tahuna Tephra is compositionally and mineralogically similar to pre-Kawakawa units from TVC. Its hornblende-dominant mineralogy, lower temperature, and higher SiO₂ content are similar to Tihoi and Okaia Tephra. In particular, hornblende and spinel in Tahuna Tephra are compositionally similar to those in TVC units, and distinct from the Mangaone Subgroup units (Fig. 4, 5). Oxygen fugacity can be characteristic of an eruptive centre for periods of 10–20 000 yr (Shane 1998). In this respect, Tahuna Tephra is more similar to Tihoi and Okaia Tephra beds from the TVC (Fig. 6). This may point to TVC as the source for Tahuna Tephra. Currently available tephra thickness data (Fig. 1) do not uniquely identify a source vent. However, the thickest exposure of Tahuna Tephra that we have examined occurs near the western side of Lake Taupo (site 58) (Fig. 1) and this is more consistent with a TVC vent. The Tahuna Tephra occurs as a 30 cm thick, coarse ash bed at Lake Poukawa (Shane et al. in press), some 190 km from OVC and c. 120 km from TVZ. Most of the rhyolitic tephra in the Lake Poukawa core have a TVC source, and the only other bed with comparable texture and thickness is the Kawakawa Tephra from TVC (Shane et al. in press). Only two OVC-sourced tephra beds are confirmed in this sequence, c. 50 000 yr Rotoehu Tephra (Lian & Shane 2000) and 4800 yr Whakatane Tephra. Both occur as fine ash pods, reflecting the distal location of Lake Poukawa relative to OVC.

It is possible that Tahuna Tephra erupted from a vent within the Maroa Volcanic Centre; however, there are no detailed geochemical data on glass or phenocrysts published from this centre to compare our data with. In addition, chronological constraints for the last 50 000 yr are limited, and dispersal maps are not available. The exact vent location for Tahuna Tephra will remain uncertain until more dispersal data are available. However, geochemical data do not support an OVC source.

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